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METEOROLOGICAL RESEARCH COMMITTEE.
AIR MINISTRY

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The nocturnal dissipation of strato-cumulus cloud

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(1) Introduction

The difficulty encountered in forecasting the dissipation or persistence of a sheet of strato-cumulus cloud suggests that the cloud layer is in a delicate state of balance with its environment.

Subsidence or ascent within the air mass at cloud heights can dissipate or reinforce the cloud sheet, whilst advective changes might transfer the layer from one locality to another. Radiation from the cloud layer produces a net flux of heat outwards and cools the cloud sheet, and mixing by eddy diffusion occurs at cloud base and top with the air below and above the layer; in addition the radiative cooling of the cloud may be sufficient to produce mixing by convective turbulence at cloud base. Generally, analysis of surface synoptic charts and radio-sonde observations gives little indication as to which processes dominate the behaviour of the cloud sheet, though instances of considerable vertical motion or advection at cloud levels would be at once evident. Thus it seemed desirable to select a number of cases and examine them statistically for significant differences between the means of the parameters (or combination of the parameters) involved, for the two classes of dissipating and non-dissipating cloud.

(2) Selection of cases

The choice of examples for statistical analysis was made from 1952-1954, and was governed by the following simple criteria.

(i) The strato-cumulus sheet was bounded at its top by a dry type inversion, i.e. a rapid decrease of humidity with height through the region of temperature increase. (This was realised in almost all cases of non-frontal strato-cumulus.)

(ii) There was no surface front within 400 miles of the locality of the cloud sheet.

(iii) The cloud base was above the condensation level of any convection from the sea, all cases being taken over land.

(iv) The cloud sheet was extensive covering perhaps several hundred square miles, and gave almost complete cover, i.e. greater than 6/8 for at least two consecutive hours. The cloud was considered to have dissipated if the sheet had reduced to 2/8 or less for at least two consecutive hours.

(v) Only nocturnal dissipation or persistence was considered because there was then no continuous maintenance of the cloud by convection from the surface.

/In general

In general, cloud bases were determined from surface observations and cloud tops from the vertical temperature profiles obtained by radio-sonde ascents at the same time. In some cases, when the cloud bases reported from the ground were not fully consistent with the vertical temperature profiles indicated by the ascents, the values of the cloud bases used were obtained by the use of the temperatures and dewpoints given by the soundings. Several cases were rejected since the cloud bases so obtained were completely at variance with those reported from the ground.

(3) Advection and vertical motion

Advective changes were rarely responsible for the dissipation of sheets of strato-cumulus cloud of the type considered. This was concluded from examination of hourly surface charts in cases when the strato-cumulus dispersed, when extensive areas of cloud present at one hour had almost completely vanished by the next. The process of dispersal when it occurred was usually quite sudden, and no cases were observed in which the edge of the cloud sheet retreated steadily with the wind as would be expected with advective clearance. It did appear, however, that local fluctuations in cloud height were often due to minor advective changes.

Consideration of the potential temperatures, humidity mixing ratios and wet-bulb potential temperatures of soundings through the air masses relevant to the cloud sheets showed little evidence that vertical motion in the atmosphere was the chief cause of the persistence or dissipation of the cloud. Although, on occasions, subsidence of the order of 4-5 mb. per hour could be detected at 700 mb. and above, little direct evidence of the influence of subsidence could be observed at cloud heights. Thus it was thought that for the cases selected, advective changes and vertical motions in the air masses were not primarily responsible for the behaviour of the cloud sheet.

(4) Radiation from the cloud

The net radiative flux from a cloud sheet was calculated for several cases by use of the Elsasser radiation chart. The loss of heat flux was of the order of 20 cal/cm^{-2} in 3 hr and varied little from case to case, being almost independent of cloud thickness. Thus the variation of radiative flux did not seem to be a principal factor in determining persistence or dissipation of the cloud sheet. To calculate the cooling of the cloud layer, the cloud was regarded as a black body, and the cooling depended greatly upon cloud thickness. Hewson (1948) has demonstrated how such cooling could be responsible for the dissipation of scattered fragments of cloud. In this process, the cloud fragments cool by radiation and sink relative to the environment, so ultimately dispersing. In considering such a mechanism, Hewson neglects any compensating up-currents in the environmental air. This is quite legitimate if the cloud comprises only isolated fragments. If, however, the cloud amount is substantial, or indeed the cloud is continuous, we cannot neglect the up-currents in such a way. They would almost certainly have the effect of continuously reforming the cloud. Thus Hewson's process cannot be invoked to explain the dissipation of a continuous sheet of strato-cumulus cloud. In this case the effect of the radiational cooling of the cloud is to establish an adiabatic lapse rate below cloud and thus convective mixing between cloud and the air below. Such convective mixing could in theory result in the dispersal of the cloud provided the sub-cloud air were sufficiently dry not to reach saturation at cloud height. It was found that the extreme dryness necessary did not occur; in fact, convective mixing with the air below cloud would in general retard rather than assist dissipation of the cloud.

In the course of carrying out the radiation calculations it was noted that the calculated amount of cooling of the cloud was considerably greater than that suggested by successive radio-sonde ascents, even after allowing for the latent heat released by additional condensation. This fact supports the idea that continuous mixing with the air above and/or below cloud must be important processes in maintaining the temperature of the cloud and these are, therefore, considered further.

(5) Turbulent mixing with air above cloud top

Turbulent mixing caused by eddy diffusion at the cloud-inversion interface would cause much warmer and drier air to enter the cloud. Consequently it was thought that there might be a significant difference between the warmth and dryness of the air above cloud for the two classes of dissipation and persistence.

The depression of the dewpoint below dry bulb temperature in °F at a given pressure level was used as a simple parameter, and Table 1 was constructed relating the persistence or dissipation of the cloud (within 12 hours of the radio-sonde ascent used) with the maximum depression up to 50 mb. above cloud top. It was thought that the standard error in estimating cloud top was such that the parameter used would be more representative than if a much smaller or much greater depth of air above cloud was taken. This was shown to be the case when tables similar to Table 1 were prepared for the dewpoint depression within 25 mb. and 100 mb. of cloud top.

Table 1

Maximum value of depression of dewpoint below temperature in °F taken over 50 mb. above cloud top

	Breaks ($\leq$ 12 hours)	No breaks
Mean (°F)	24	18
Standard deviation	13	14
Standard error of mean	2.6	2.7
No. of cases	26	27

Student's 't' evaluated for the difference between the means in Table 1 gave t = 1.60 which showed that the means were significantly different at about the 10% level. The dryness of the air above cloud must, therefore, be relevant to the problem of dissipation.

(6) Turbulent mixing with air below cloud base

In all of the cases examined the air below cloud was not sufficiently dry for any mixing at cloud base to produce dissipation of the cloud. The radiative cooling of the cloud was usually great enough for the establishment of a dry adiabatic layer directly below cloud, so that mixing by convective turbulence as well as eddy diffusion took place at these levels. Hence these processes probably acted as a retarding factor on any dissipating mechanism produced by mixing through the inversion.

Table 2 presents the means and standard deviations of the hydrolapses averaged over 50 mb. below cloud base for cases of "Breaks" and "No breaks" of the strato-cumulus sheets.

Table 2

Hydrolapses over 50 mb. below cloud in 10^{-2} gm/Kg per mb.

	Breaks ($\leq$ 12 hours)	No breaks
Mean ($\times 10^{-2}$ gm/Kg per mb.)	1.1	1.5
Standard deviation	0.8	0.8
Standard error of mean	0.16	0.16
No. of cases	26	27

Evaluation of Student's 't' for the means above gave t = 1.77 which indicated that the means were significantly different at about the 10% level.

/(7)

(7) Effect of cloud thickness

Table 3 presents the means and standard deviations of the observations of cloud thickness in mb. for the two classes of "Breaks" and "No breaks".

Table 3

Cloud thickness in mb.

	Breaks ($\leq$ 12 hours)	No breaks
Mean (mb.)	33.5	43.5
Standard deviation	20.0	19.0
Standard error of the mean	3.9	3.9
No. of cases	26	27

For the above means, Student's 't' = 1.86, which showed that the difference between the means was significantly different from zero at about the 10% level.

(8) Combination of the parameters

Tables 1, 2, and 3 suggested that it would be worth devising a new parameter by a combination of the three variables used in the preparation of the tables. The new parameter was defined as $\xi = x + \alpha y + \beta z$ where x, y, z, were the three variables used above, and α and β were constants, to be determined by the condition that the departure from zero of the difference between the means of ξ for cases of "Breaks" and "No breaks" should have maximum significance. The conditions were determined by maximising Student's 't' for the difference between the two means of ξ, and the final parameter obtained as:-

$$\xi = x - 9.15\, y - 0.77\, z$$

where x = Maximum depression in °F of dewpoint below temperature at any pressure level up to 50 mb. above cloud top,

y = Average hydrolapse in 10^{-2} gm/Kg per mb. over 50 mb. below cloud base, and z = Cloud thickness in mb.

Table 4 presents the means and standard deviations of ξ for the two classes of cloud behaviour.

Table 4. $\xi = x - 9.15\, y - 0.77\, z$

	Breaks ($\leq$ 12 hours)	No breaks
Mean	-12.1	-28.4
Standard deviation	18.9	16.4
Standard error of the mean	3.71	3.35
No. of cases	26	27

Student's 't' now gives t = 3.36, which indicates that the means are significantly different at about the 0.2% level; the form of ξ is the best relationship that can be obtained by a linear combination of the three parameters used.

Fig. 1 shows the distribution of values of ξ for cases of "Breaks" and "No breaks". 74% of the cases of "No breaks" have values of ξ less than - 20, whilst 76% of the cases of "Breaks" have values of ξ greater than - 20.

These figures would be somewhat better were it not for two cases of each type which fall well to the wrong side of the dividing line at ξ = -20. These cases are perhaps worthy of some discussion if only to illustrate the difficulties encountered.

/(a)

(a) One case of dissipating cloud gives ξ = -65.8 which is well to the wrong side of the dividing line at ξ = -20. This large value is given mainly by an assessed cloud thickness of 90 mb., which was consistent with the observations of cloud base (2,500 to 3,000 ft.). However, a thickness of 30 mb. is easily possible from the ascent, but this would require a cloud base of 4,500 ft.

(b) A second case of dissipating cloud gives ξ = -60.2 which is again to the wrong side of the dividing line. The cloud thickness used in this case was 30 mb., although any value up to 70 mb. was possible, and hence uncertainties in the cloud thickness alone could not have been responsible for the excessively large value of ξ. The hydrolapse above cloud had a shallow slope, but was verified by comparison with other soundings in the same air mass.

(c) One case of persisting cloud gives ξ = 14.1, well to the wrong side of ξ = -20. This discrepancy is again attributed to lack of definite information regarding cloud base and top. A thickness of 10 mb. was used in the statistical study implying a cloud base of 4,000 ft. This was a case when the surface reports of cloud base were rejected in favour of assessment from the ascent. Had the surface observations been accepted (2,000 to 3,000 ft.), a value for cloud thickness of from 120 to 70 mb. would have been indicated. It is possible, of course, that there were two layers in this case.

(d) The final point well to the wrong side of ξ = -20 is given by ξ = 19.6 for persisting cloud. The cloud was assumed to be 35 mb. thick with a base of 4,000 ft., although surface observations were reporting the base as 2,000-3,000 ft. It is possible that there could have been two cloud layers, the first as already assumed, and the second base 2,000 ft. and thickness 35 mb. The air above this lower layer was not very dry, and it is also possible that the layer was being reinforced by convection from sea surface.

It is concluded from the above that the most glaring discrepancies in the indication provided by the combined parameter ξ almost certainly arise owing to the difficulties and uncertainties of assessing cloud thicknesses in the absence of positive information.

(9) Conclusions

(i) In the cases examined, there was little evidence to show that vertical motion in the atmosphere was responsible for the dispersal or persistence of strato-cumulus cloud.

(ii) Hewson's processes for the dissipation of broken and scattered cloud by differential radiation could not explain the dispersal of a continuous sheet of cloud. Although mixing at cloud base with air below was always present, exceedingly dry air below cloud would have been required for dissipation.

(iii) Radiative cooling of the cloud sheet caused an intensification of the mixing process at cloud base, and could not produce dissipation of the cloud.

(iv) Turbulent mixing of the cloud with the dry air above seemed to be significant in the subsequent behaviour of the cloud.

(v) A combination of three parameters expressing the warmth and dryness of the air above cloud, the hydrolapse below cloud, and cloud thickness gave means, the difference between which differed significantly from zero for cases of "Breaks" and "No breaks". This result may be of some value for forecasting.

/(vi)

(vi) If mixing with the air above and below a strato-cumulus layer is the main controlling process determining whether the cloud layer will persist or dissipate, it is doubtful whether any more specific criteria for the dispersal of the cloud can be developed on the basis of synoptic observations because of their limitations for determining the essential parameters, - cloud thickness and humidity distribution above and below cloud.

Before any more detailed routine observations are recommended a better physical understanding of the mixing process is required, and it is suggested that the next stage in research on the behaviour of strato-cumulus should be a study of this process based on temperature, humidity and accelerometer readings by aircraft immediately above and below the cloud layer. In addition observations of liquid water content in such cloud would be useful.

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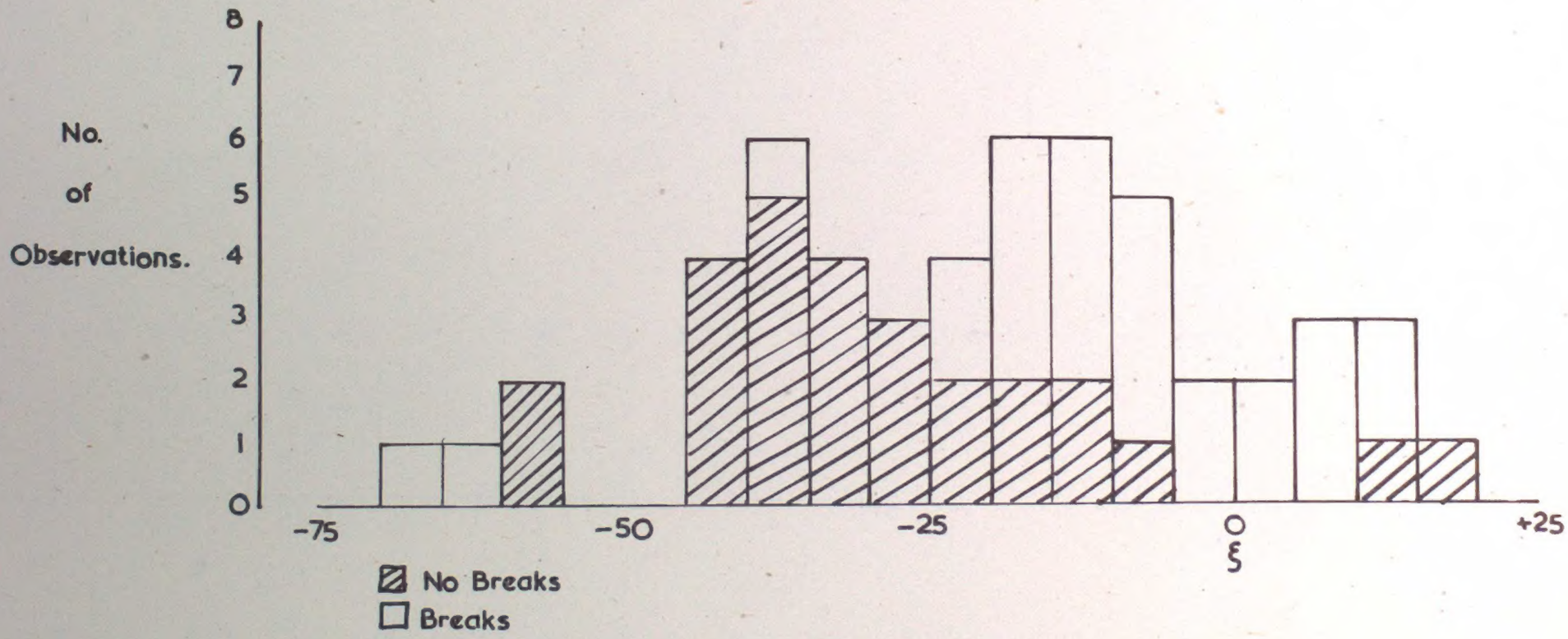
Fig. 1 Frequency of Cases with Values of $\xi = x - 9{\cdot}15y - 0{\cdot}77z$